MHD Energy Bypass Engine: A Progress Report

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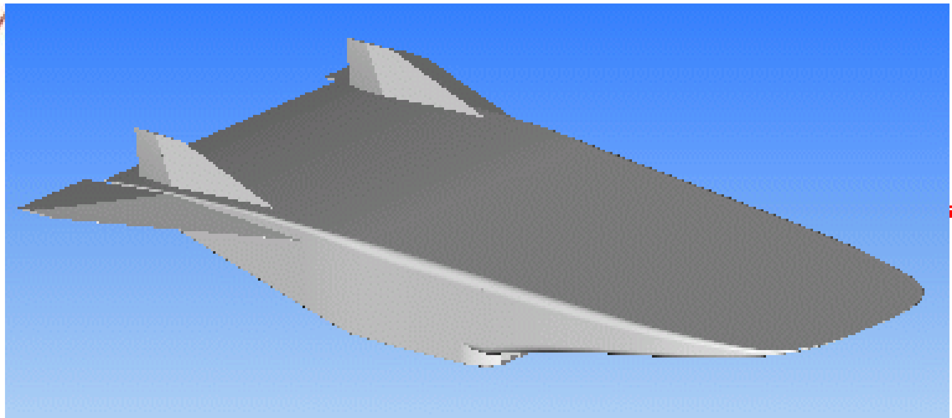
Outline

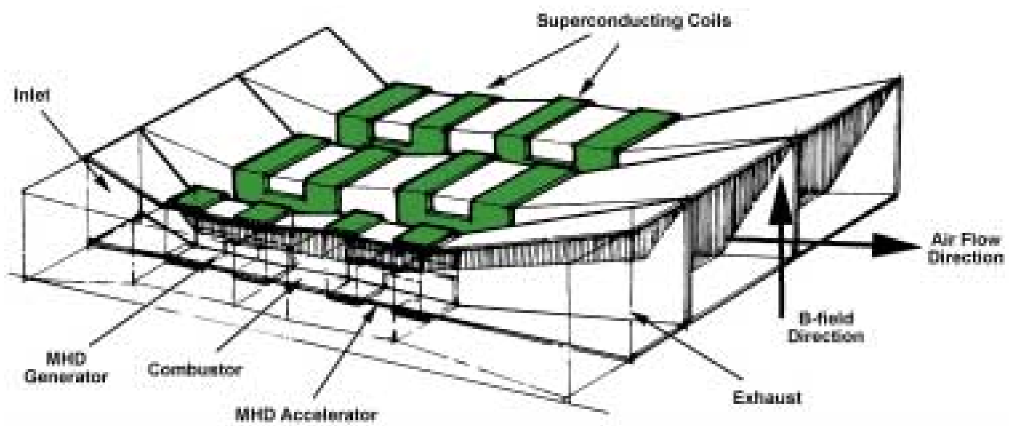
- Motivation and Objective
- Equilibrium ionization versus nonequilibrium ionization
- National MHD Accelerator Facility



Electromagnetic Energy Management

- Objective
  - Hypersonic AYAKS-type concept evaluation, research, technology, and development
- Output
  - Assessment of MHD energy bypass engine concepts for space transportation
  - National MHD Accelerator Facility
- Outcome
  - AYAKS-type concepts may contribute to reducing cost to access space and enable global reach
  - Increased enthalpy levels for testing in the ARC’s 20 MW arc-jet facility

Major MHD Issues



- **Air Ionization**
  - Equilibrium vs. non-equilibrium
  - Electrical conductivity
  - Power density requirement
- **Flight-Weight Magnets**
  - Superconductor technology
  - Ultra-light-weight assemblies
- **Intelligent Controls**
- **MHD Performance**
  - Accelerator performance
    - Optimum load factors
    - Losses in boundary layers
  - Optimal design of MHD devices
  - Generator-accelerator coupling

MHD Energy Bypass Scramjet Propulsion: Research, Technology, and Development

Goal

Contribute to NASA's goal, increase safety and reduce cost for space transportation, by significantly improving the scramjet performance and reliability

Project Objective

Energy management with MHD for improved scramjet performance

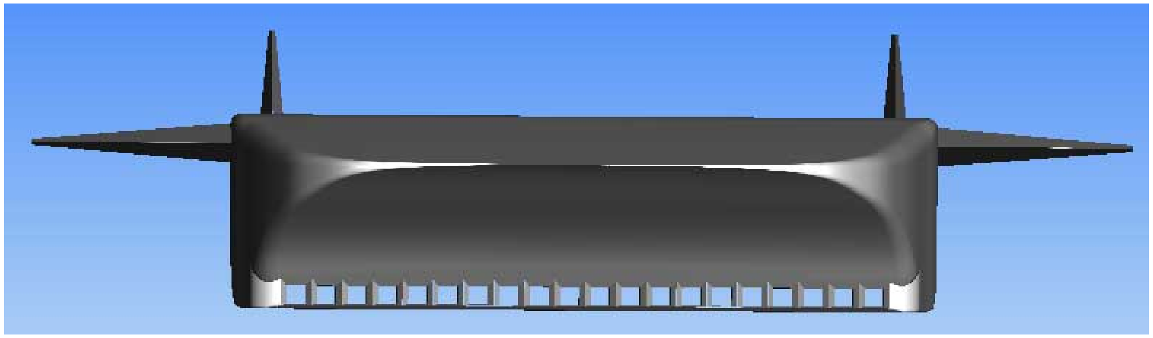
Tech Challenges

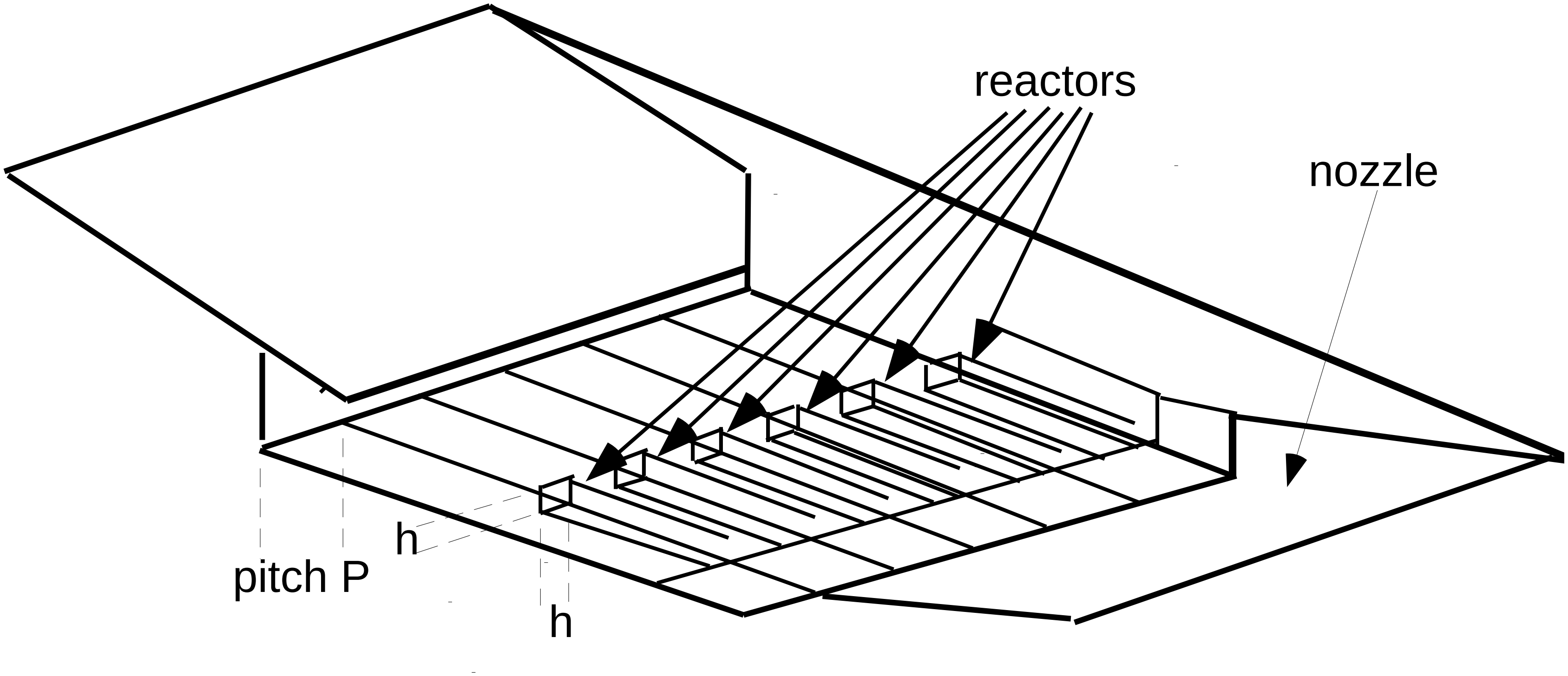
- Airframe/Engine Integration
- Ionization of Air
- MHD Accelerator
- Flight-Weight MHD Devices

Approaches

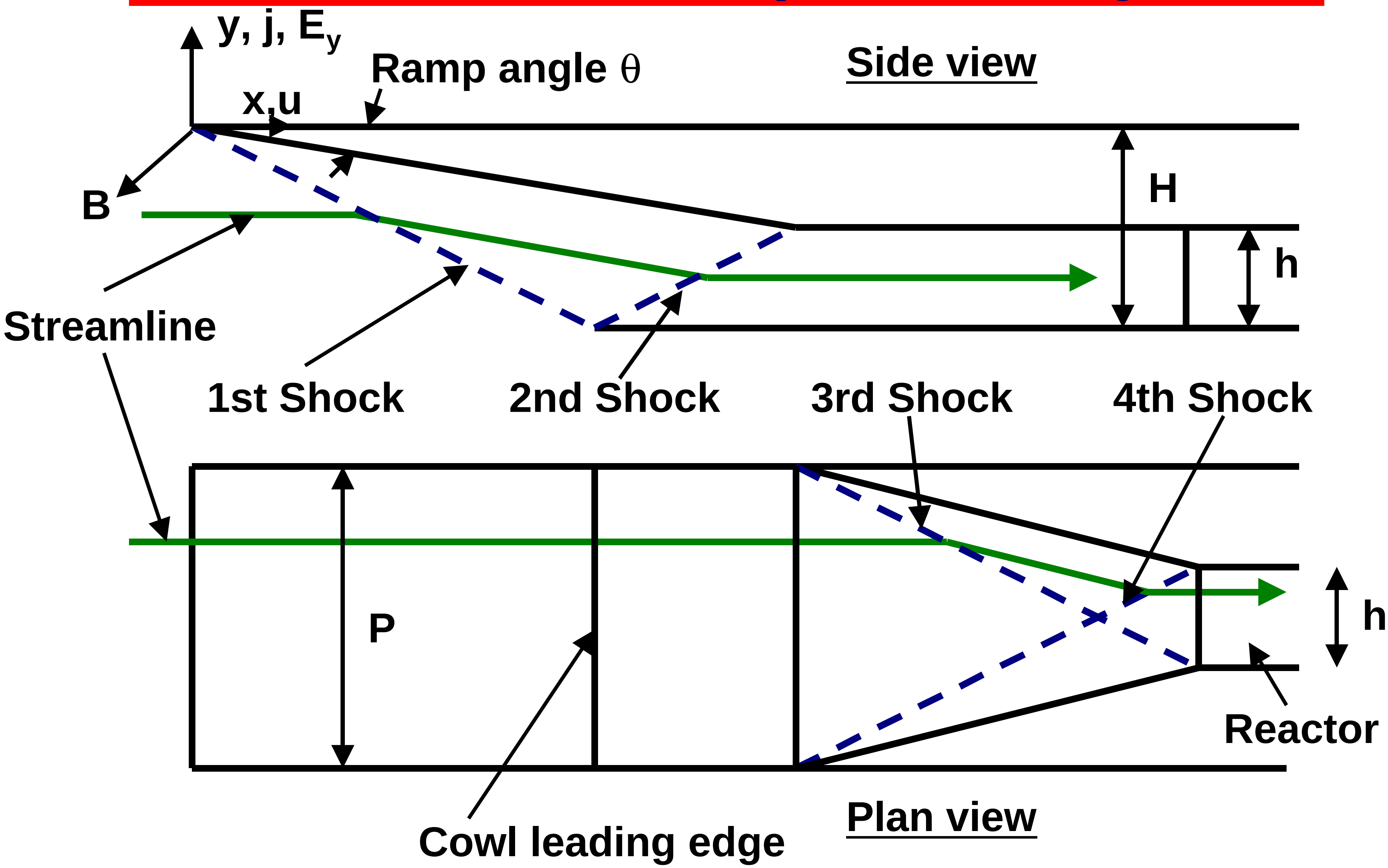
- Vehicle Analysis
- Development of Integrated Tools
- Facility Development & Experimental Studies: Ionization & Lorentz Forces
  - EAST Facility
  - Arc-Jet Facility
- Theoretical Studies
  - Non-equilibrium Ionization
  - Equilibrium Ionization
  - Advanced Tools Development
- Conductive and Non-conductive, ultra-high temperature materials and magnets

Schematic View of a Spaceliner





Propulsive Flow Path Along A Two-Plane Compression System

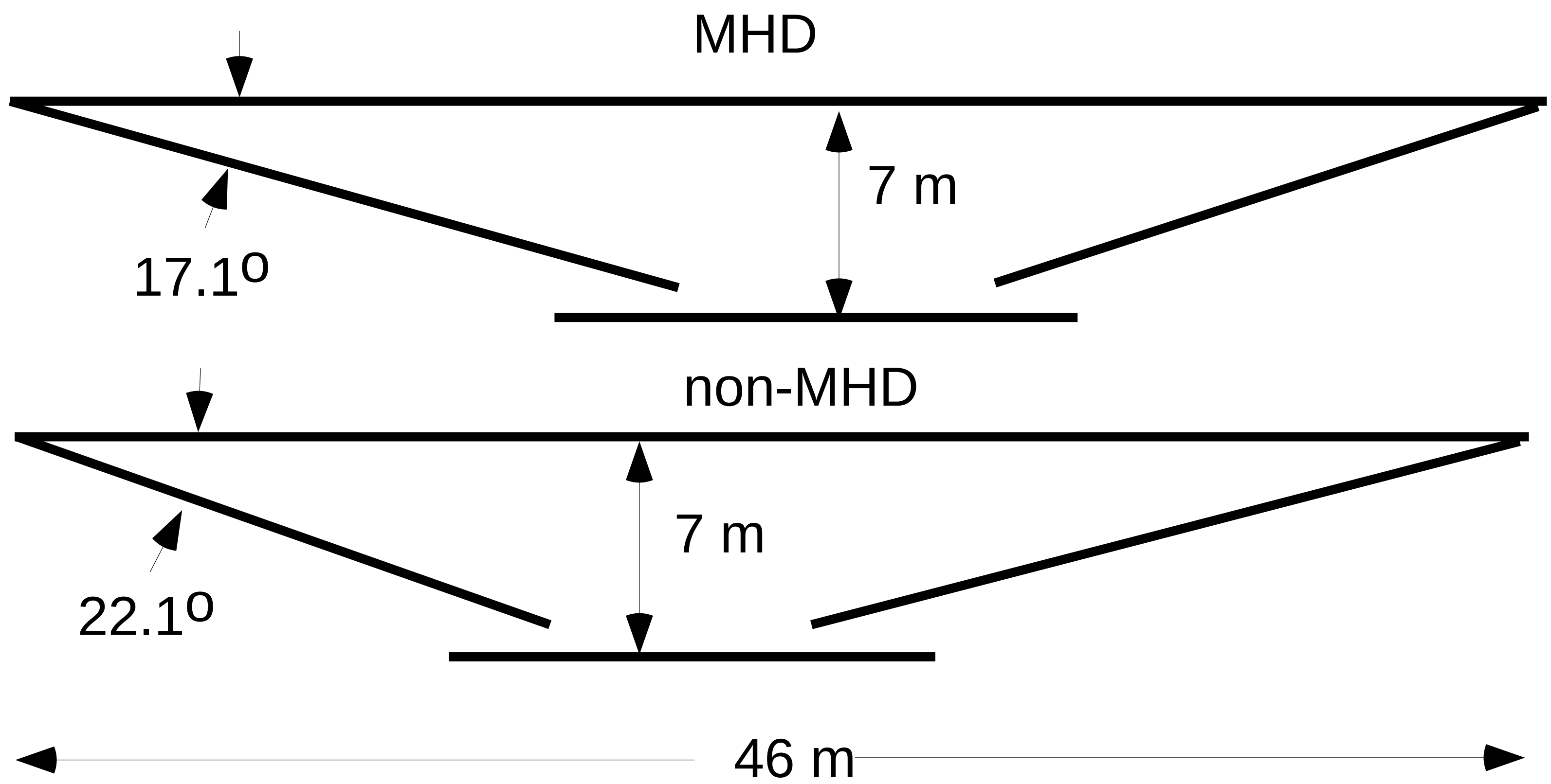


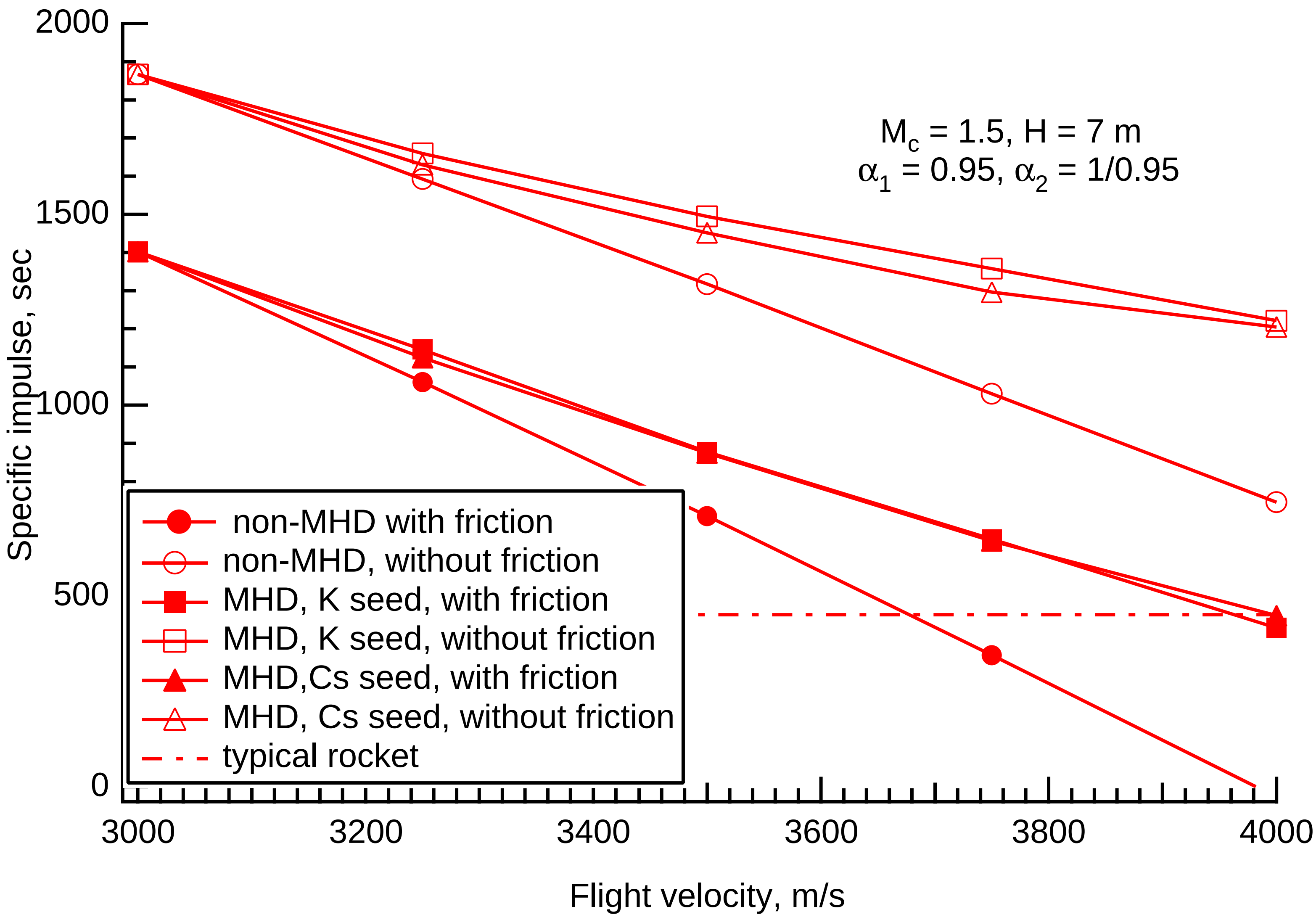
Shock waves and cesium or potassium seed assist in achieving equilibrium ionization.

Optimum Configurations

(V = 3.75 km/s, M_c = 1.5, H = 7 m, α_1 = 1/0.95, α_2 = 0.95)

Two-plane compression system





Mc = 1.5, H = 7 m
α1 = 0.95, α2 = 1/0.95
2000
1500
1000
500
0
3000
3200
3400
3600
3800
4000
Specific impulse, sec
Flight velocity, m/s
non-MHD with friction
non-MHD, without friction
MHD, K seed, with friction
MHD, K seed, without friction
MHD,Cs seed, with friction
MHD, Cs seed, without friction
typical rocket

Overall Performance

(V = 3.75 km/s, M_c = 1.5, α_1 = 1/0.95, α_2 = 0.95)

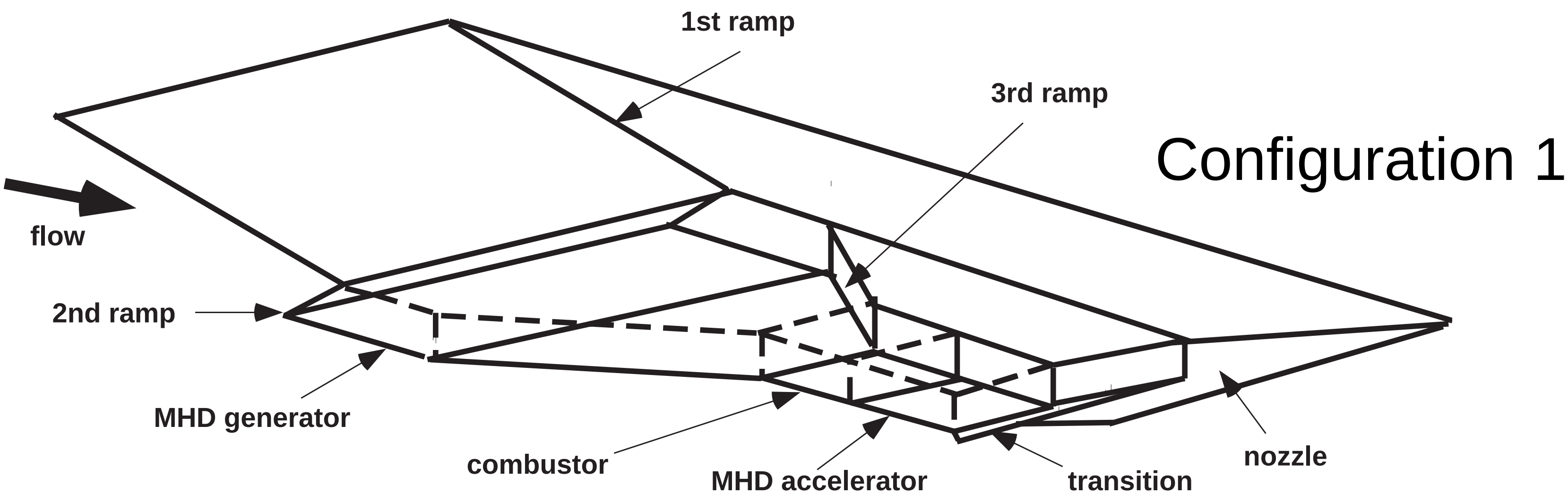
MHD Devices

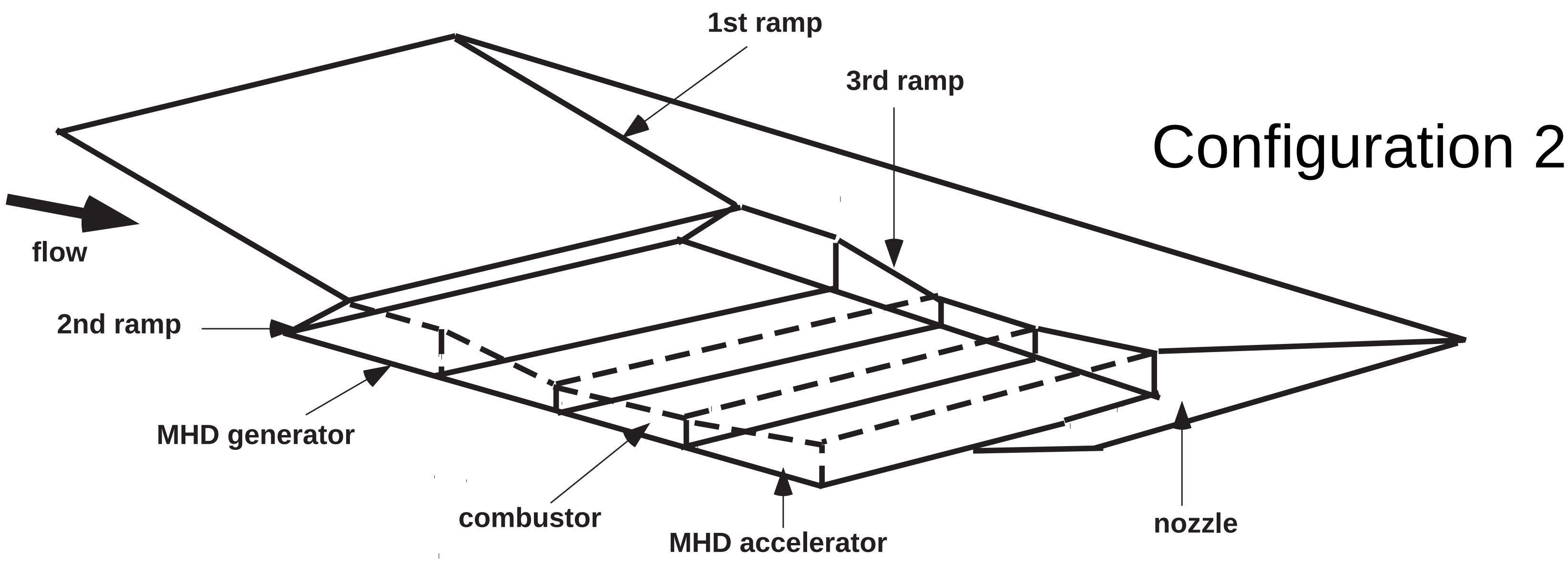
	Generator	*Accelerator*
Electrical conductivity	32.42 mho/m	35.87 mho/m
Ionization fraction	4.294×10^{-5}	5.583×10^{-5}
Magnetic field	12.74 Tesla	11.28 Tesla
Hall parameter (avg.)	3.524	2.319
Current density (avg.)	-6.6×10^{4} A/m^2	3.96×10^{4} A/m^2
Power transferred	6.85×10^{8} W/m	6.85×10^{8} W/m

Vehicle performance

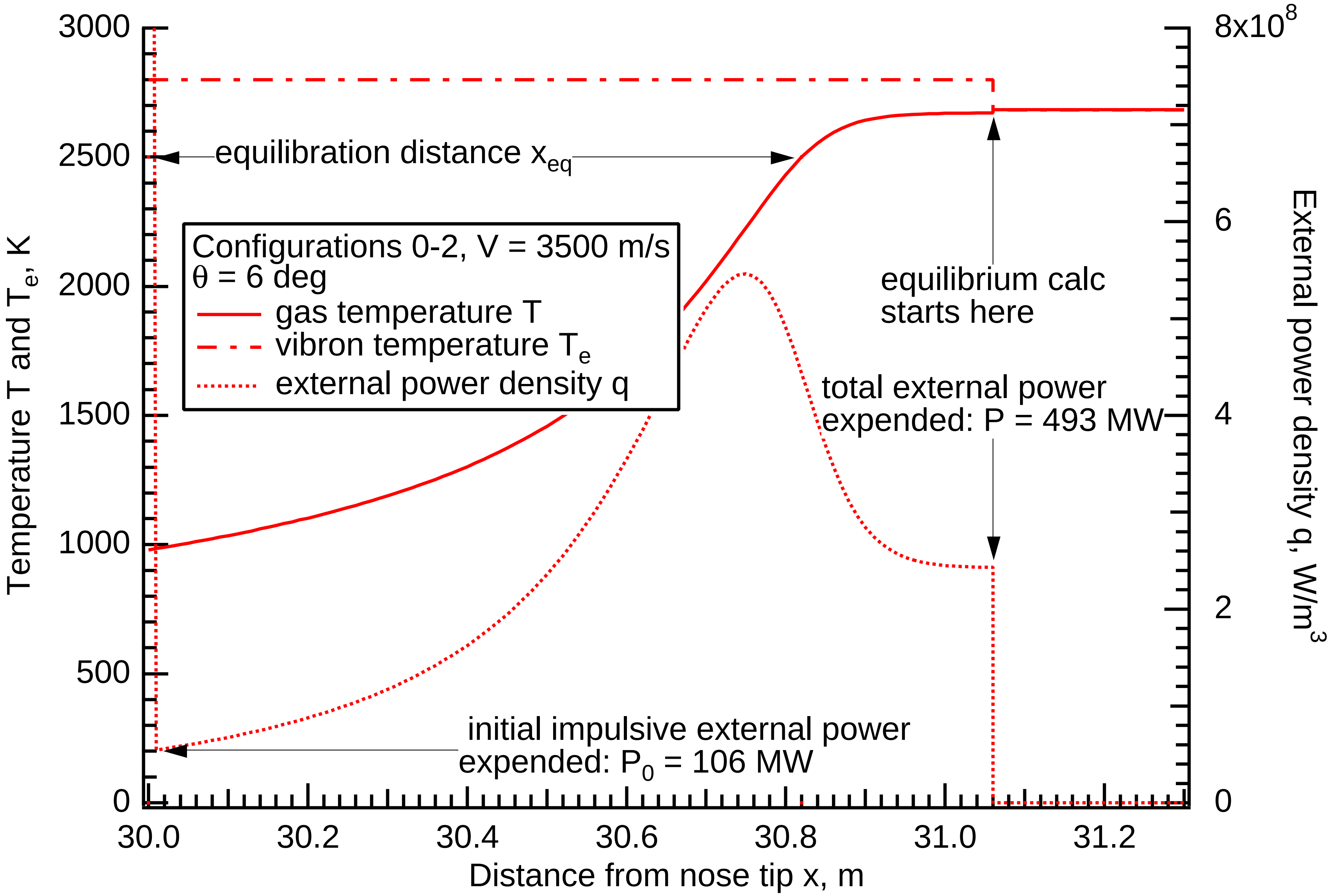
Energy bypass ratio	0.282
Specific impulse	649.5 sec

Four-Shock Designs

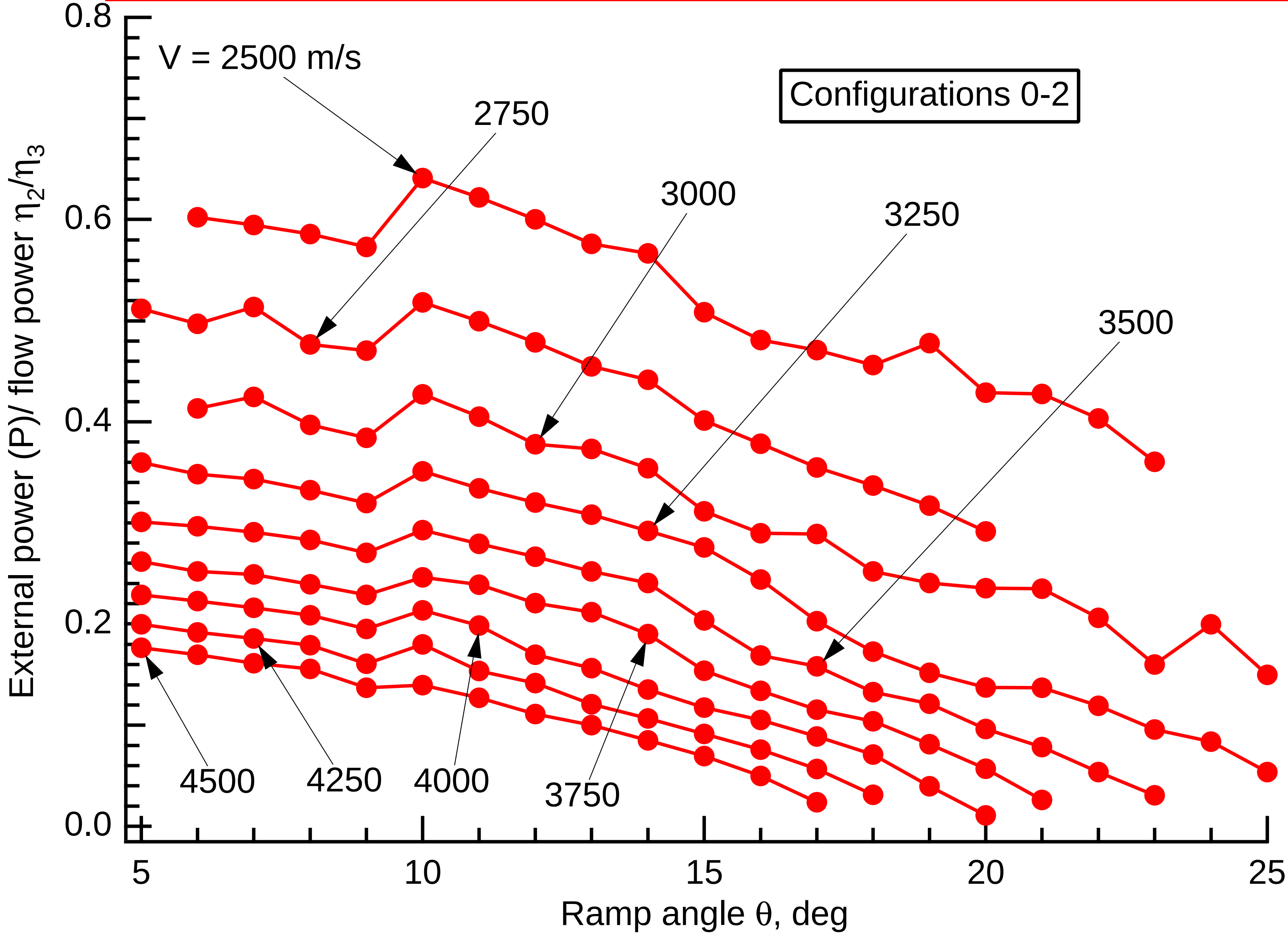




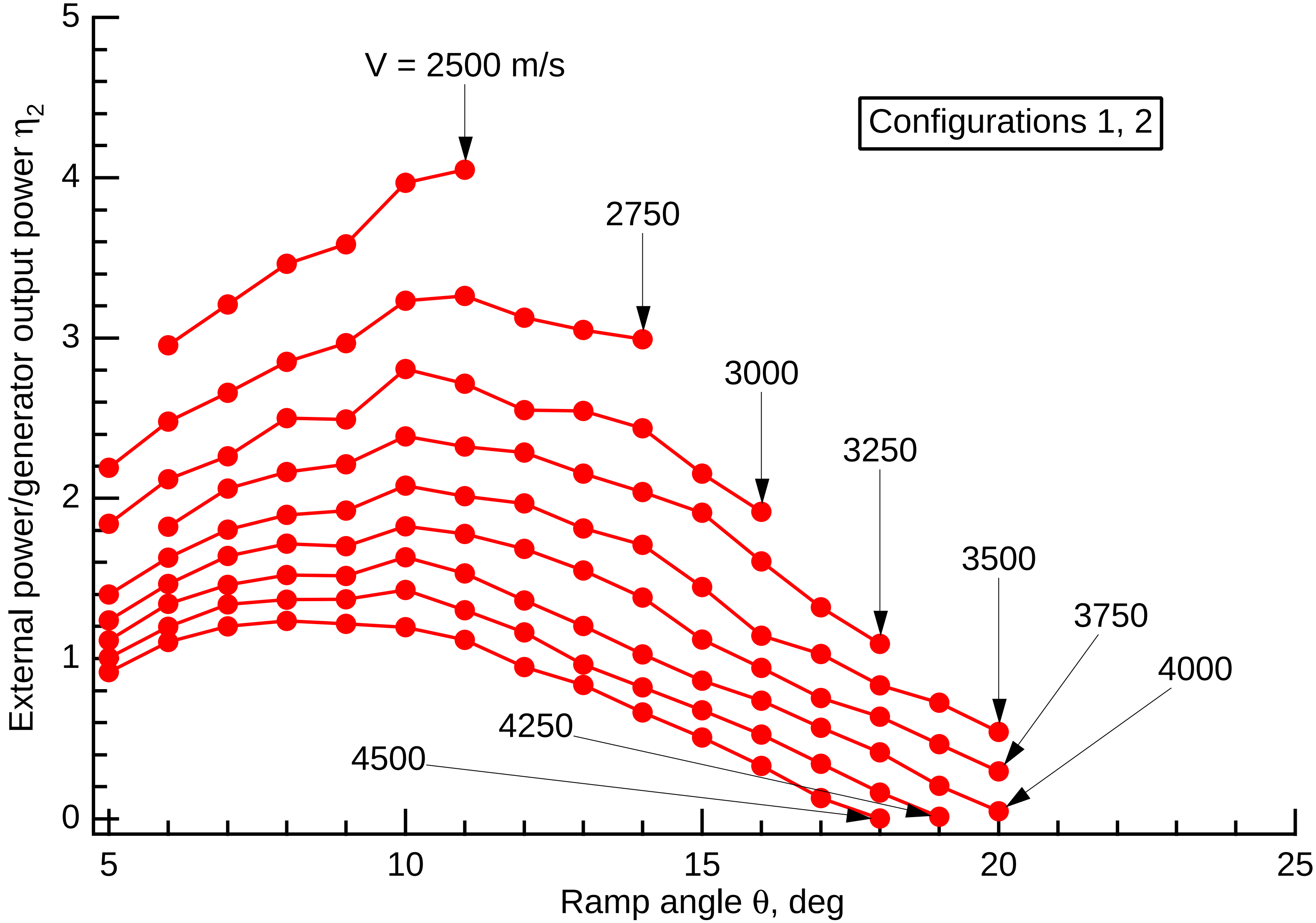
Typical Variation of Gas Temperature and Required External Power



External-to-Flow Power Ratio

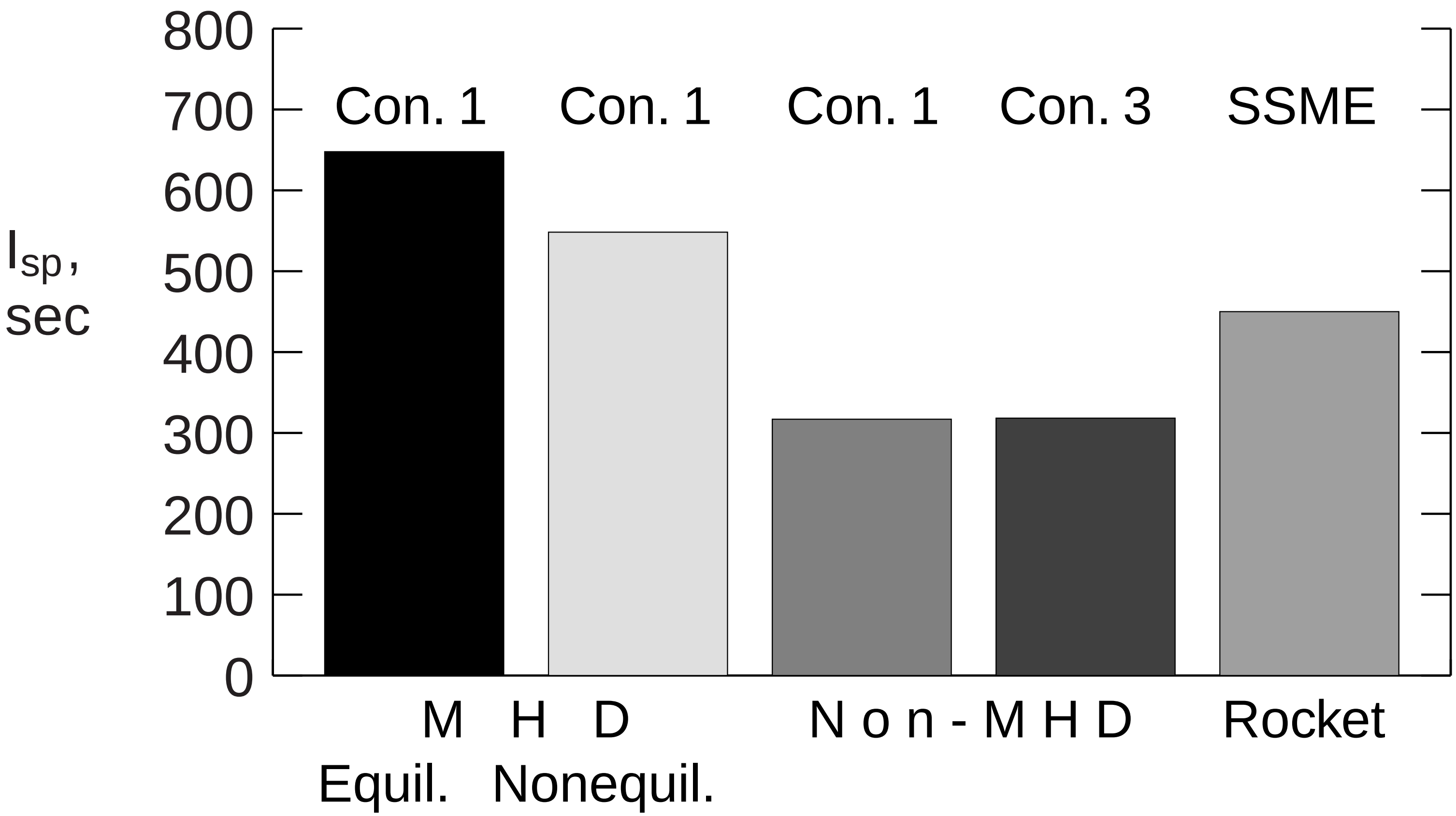


External-to-Generator Power Ratio



Comparison of Specific Impulses

$V = 3.75$ km/s, $q = 1$ atm, $M_c < 1.503$,
$m_f = 378.3$ kg/s/m, Vehicle height = 7 m, Comb. = 0.45 m
MHD gen. length = 2.72 m, & MHD accel. length = 2.85 m



MHD Accelerator Facility Program

Objective …

- **National Facility for MHD-Bypass Engine Technology**
  - Demonstrate MHD accelerator technology
  - Validate theoretical/computational predictive tools
  - Create National MHD Accelerator Facility

Approach …

- **Technology demonstration project s**
  - Conduct a pilot MHD accelerator study in the EAST Facility at NASA Ames Research Center (ARC)
  - NASA MSFC Phase III FAST Track of Air Force Phase II SBIR with LyTEC LLC as prime contractor
    - Design and demonstrate a pilot MHD accelerator for 1MW arc-jet at MSFC
    - Design an MHD accelerator of 20MW arc-jet at ARC
- **Develop National Facility at NASA ARC**
  - EAST MHD Accelerator Facility
  - Arc-Jet MHD Accelerator Facility

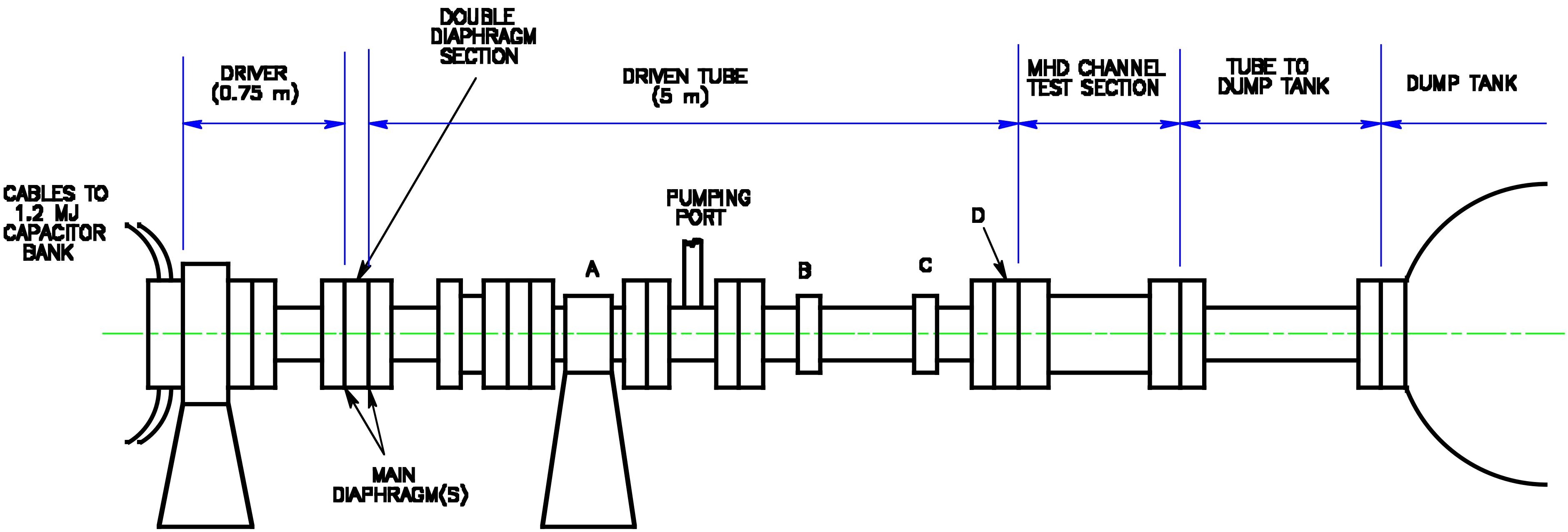
MHD Accelerator in the EAST Facility: Objectives

- Determine
  - Back EMFs (no power input)
  - Flow acceleration and joule heating
  - Best load factor and Hall parameter attainable
- Measure true conductivity, with and without magnetic field
- Investigate
  - Shorting in parallel boundary layers due to locally high load factor
  - Energy loss in perpendicular boundary layers due to cathode and anode fall heating
  - Faraday connected channel (Hall connected channel possible later)

Electric Arc Shock Tube (EAST)

NOTES:

TUBE DIAMETER IS 10 CM.
LETTERS A THROUGH D DENOTE
SHOCK VELOCITY MEASURING STATIONS
UPSTREAM OF MHD TEST SECTION



NASA AMES EAST FACILITY SET UP
FOR MHD EXPERIMENTS

MHD Accelerator: Assembly

Internal Views of the MHD Accerator

Assembly with Current Feed and Magnetic Field Current Conductors

Magnetic Field Current Feed

Magnetic Field Current Conductors

Pitot Rake

MHD Channel Operating Conditions

- Static pressure: 0.5 - 1.5 atm.
- Temperature: 3000 - 6000 K
- Magnetic field: 1.5 - 4 Tesla
- Mach Number: 2.0
- Hall parameter: approx. 5
- Interaction parameter: $(jBL)/(\rho u^2) \approx \Delta u/u = 0.2 - 0.5$
- Load factor: $E / (uB) = 2 \rightarrow 1.2$
- The MHD device can be run as an accelerator or a generator and with or without seed.

Diagnostics

- **Diagnostics**
  - Shock velocity
  - Static pressures
  - light emission at nozzle entrance and upstream of channel entrance to determine test time
  - Impact pressure rake at channel exit
  - Main electrode currents and voltages
  - Floating potential voltages (for conductivity measurements)
- **Other possible diagnostics**
  - CCD camera movies may be taken to show oblique shock angles and thus, Mach number. Temperature may be obtainable spectroscopically from line intensity measurements.
- **A data acquistion system with 48 channels and a speed of 1 MHz is available. Eight channels can be run at speeds up to 10 MHz and 36 channels at 1 MHz can be converted to 9 channels at 5 MHz, if required.**

Conclusions

- The energy management with electromagnetic forces and facilitated by equilibrium ionization could enhance the performance of scramjet.
  – SSTO spaceplane
  – First stage of a TSTO spaceplane & globecruiser
- The MHD accelerator for the EAST Facility is built.